Energy audit of BPCL Building at Noida

Prepared for **Bharat Petroleum Corporation Ltd, Noida**

TERI Project Report No. 2002IE65

Draft
Nov. 2002

Energy audit of BPCL Building at Noida

Prepared for **Bharat Petroleum Corporation Ltd, Noida**

TERI Project Report No. 2002IE65

Acknowledgements

Bharat Petroleum Corporation Limited (BPCL) for entrusting TERI for this project.

Mr Babar Hameed, Manager Administration - North for providing his support, expert comments and extending excellent hospitality to the TERI energy audit team throughout the project.

Mr Ashish Rastogi, Senior Engineer, and his team in field measurement and for providing system details, technical information and help to us.

Our thanks are also to Ms Tina Alawadi and Mr G Gopalakrishnan for assistance in typing and applying finishing touches to the report.

Contents

Executive Summary

Chapter 1 Energy analysis **page no.**

1.1 Connected load pattern 1
1.2 Energy consumption pattern 3
1.3 Energy cost 3
1.4 Energy demand 4
1.5 Building load on a typical summer day 5
1.6 Energy performance index 5

Chapter 2 Electrical systems

2.1 Transformers 8
2.2 Transformer loading 9
2.3 Power quality study 11
2.4 Motor load test 12
2.5 Power factor 15

Chapter 3 Lighting systems

3.1 Lighting system connected load 19
3.2 Existing lighting schemes 20
3.2 Lighting system consumption pattern 21
3.4 Measured and recommended illumination levels 22
3.5 Energy conservation options 23
3.3 Energy saving potential in lighting systems 26

Chapter 4 HVAC systems

4.1 AC system details 27
4.2 AC system connected load pattern 27
4.3 AC system consumption pattern 28
4.4 Observations and measurements 30
4.5 Energy conservation opportunities 37
4.6 Recommendations for AC system 41

Executive summary

Major findings of the study

- The total connected load at BPCL of energy system is approximately 1063 kW or 104 W/m^2.
- HVAC system accounts for 72% of the total connected load. Lighting system share is 17 %.
- The highest peak demand, which has been observed at BPCL building, is 1210 kW, which is even, less than the sanctioned demand (1318 kW).
- The annual average electricity consumption at BPCL is approximately 1865635 kWh.
- Since BPCL pays only for electricity and HSD, which is used in in-house power generation, comes free, the annual fuel cost at BPCL is around 75 lakhs. However if HSD is to be purchased then total energy cost would be approximately 86 lakhs per year.
- Energy utilization indices (EUI) defined as total energy consumed divided by total built-up area and used to compare the energy efficiency of two similar types of buildings. At BPCL, EUI is found to be 181 kWh/m^2. Present studies reveal that a fully air-conditioned efficient building in composite climate consumes generally less than 120 kWh/m^2.
- There are two transformers each of 1000KVA rating are installed to step down incoming power at 11kV to 0.433 kV.
- The average loading of transformers in summer months are 52% and 50% however, in months it drops to 29% and 30% respectively. The summer months loading are more than the rated peak efficiency loading (38.5%) and winter it gets lower than peak efficiency loading.
- Power supply has been very erratic during peak summer and monsoon months and this leads to the higher outages and poor voltage levels in these months when building load is highest.
- It is advisable to shift plant load entirely on DGs during these months and install automatic voltage-regulating device to control the high voltage & fluctuations of grid supply.
- Motor load test which was carried out on 23 motors reveal that 6 motors are operating at a load which lies between 40 to 80% of their rated load while rest are loaded below 40%.
- Since the under loaded motors of lower ratings and replacing them which lower sized motor would definitely enhance their loading percentage but

would not yield and substantial savings since the efficiency would not change much.

- The monthly average power factor of BPCL building varies between 0.79 to 0.86. Most of the buildings are supposed to pay penalty when they maintain a power factor less than 0.85. Right now power contract does not include any penalty but in future they may change. Auto power factor correction relay, which is currently installed at sub station, is not functional. Making this functional would be sufficient to maintain a power factor of around 0.95 at BPCL building.
- The lighting scheme in BPCL building was designed for a load of 278 kW with maximum consumption of 1070300 kWh per year.
- By replacing all the incandescent lamps with compact fluorescent lamps lighting load can be reduced to 181 kW (a reduction of 98 kW) and the maximum consumption would be reduced to 696850 kWh per year (a reduction of 373450 kWh).
- Replacement of T-12 & T-8 tube lights with T-5 lamps would reduce lighting load to 132 kW and the estimated maximum consumption would be 508431 kWh per year.
- Replacement of low voltage halogens with 9 W CFL in specially designed fixtures would reduce lighting load to 97 kW and the estimated maximum consumption would be 373450 kWh per year.
- With all conservation efforts lighting load can be reduced from 278 kW to 97 kW and the maximum consumption would be reduced to 373450 kWh per year from 1070300 kWh per year. Hence, in lighting system there exists a saving potential of 65% per year.
- The installed AC system load at BPCL is 768 kW. Compressor accounts for 47%, chilled water pumps 16%, condenser water pumps 16%, AHUs 18% and remaining 3% is cooling tower load.
- The estimated annual energy consumption in AC systems is approximately 9.78 lakhs units which is around 53% of the total energy consumed in BPCL building.
- In AC system plants account for 57% of the total AC consumption, pumps 27%, AHUs 14% and remaining 2% is consumed in cooling towers.
- From May till August power supply remains very erratic and that has significant effect on the over all performance of the AC systems. They operate at a very low efficiency. Following recommendations are for efficient operation of AC systems:

1. First and foremost resolve the problem of delay in start of chilling plants during periods of frequent power failures. This may be overcome by installing auto changer & auto voltage regulator.
2. Enhance the operating efficiency of chilled water pumps & condenser water pumps. This could be done with assistance of pumps' manufacturer.
3. Operate only two plants with two chilled water pumps, two condenser water pumps and only two cooling towers.
4. Reset the thermostat at 24 ° C in AHUs as compared to the existing lowest setting, which is done in order to achieve fast cooling at the time of erratic power supply.
5. Monitor plant consumption and system consumption on daily basis. A separate submeter can be installed at AC panel for this.
6. Conduct a fresh energy audit of AC system after one year of smooth operation of AC system.

- Hence there exists an energy saving potential of 203834 kWh annually or cost saving of Rs 8.8 lakhs per year by enhancing first the operating efficiency of the AC equipment and then of whole AC system. With this the system specific power consumption would decrease to 1.09 kW/TR which is even lower than the rated system specific power of 1.29 kW/TR.
- The total energy saving potential at BPCL works out be approximately 527234 kWh, which is approximately 28% of the present consumption.

1

Energy analysis

The Bharat Petroleum Corporation Limited (BPCL) plans to implement effective energy management practices in all its office buildings. They have already realised the fact that only good operating practices and maintenance schedules alone cannot reduce the energy wastage in operating energy systems since energy efficiency was never considered as a design parameter during planning and designing stages of building and building systems. Tata Energy Research Institute (TERI), New Delhi, has carried out a study in form of energy audit and it is considered as a first step towards developing comprehensive energy management program to optimise energy use in energy consuming systems at BPCL Northern Zone head office at Noida in UP.

BPCL office is a nine-storey fully air-conditioned building with parking basement. The building was commissioned in early ninety and has seen some changes both in building and its systems. The management, particularly the engineering and maintenance departments are well aware of the importance of energy costs to profitability and some efforts are already made to conserve energy in the building. Replacement of inefficient lamps with energy efficient compact fluorescent lamps in both working and non-working areas is an important example of energy conservation measures that have already been implemented.

Connected load pattern

The total connected load at the building is approximately 1063kW, which is less than the sanctioned load. The HVAC system contributes 72% and lighting systems 17% to the total load. Office equipment shares around 3% of the total connected load and the other load is 8%.

The total load density is around 104 W/m^2. HVAC load is 75 W/m^2 generally in efficient buildings it varies between 40 to 60 W/m^2. Lighting load density is approximately 18 W/m^2, which is less than the load in generally assumed in heat load calculation for HVAC system design. Anything less than 15 W/m^2 is considered as efficient lighting in office buildings designed to provide illumination levels as per Indian standards.

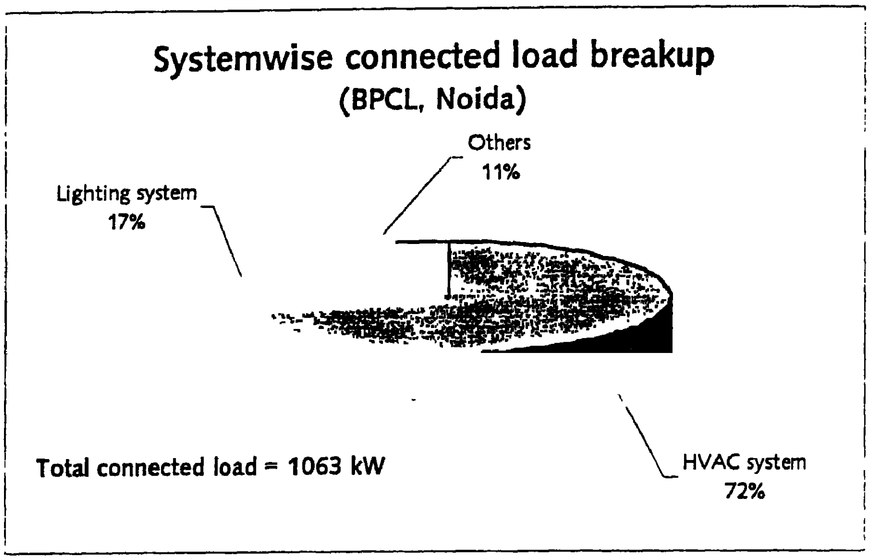

Figure 1.1

Load density

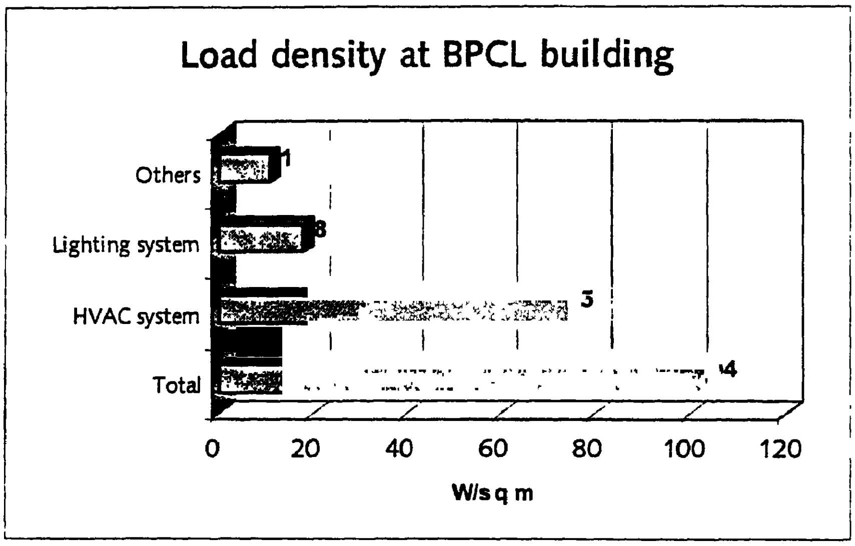

Figure 1.2

Energy consumption pattern

The different sources of energy used in BPCL are electricity and high speed diesel oil (HSD. Electricity is mainly used for space conditioning, lighting, and in the kitchen and other equipment, whereas HSD is used for in-house power generation. It has been observed that power situation is very erratic and DG sets are used very frequently.

The average total energy consumption that includes both purchased and generated electricity at BPCL building is approximately 1865635 kWh. The weather impact of on monthly total energy consumption is quite significant at BPCL building. In summer the average monthly consumption is 177364 kWh and in winter it amounts to approximately 111680 kWh.

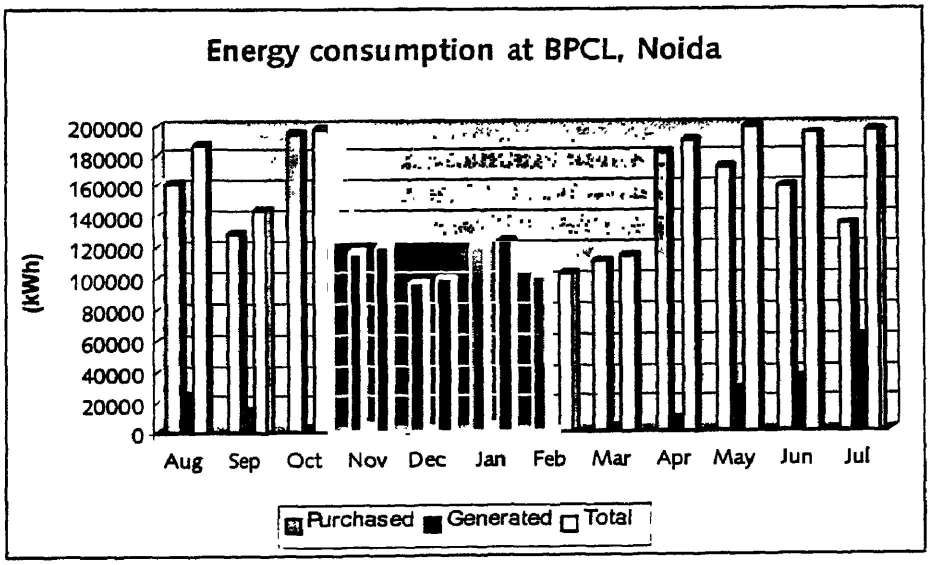

Figure 1.3

Approximately 90% of the electricity consumed in BPCL building is purchased from electricity board and remaining 10% is generated in house annually however, in summer this ratio changes and may go as high as 69:31.

The maximum energy consumption is occurred in the month of May (198510 kWh) and the minimum in December (99360 kWh).

Energy cost

The annual energy cost, which BPCL has to pay to Power Corporation, based on present energy tariff, is approximately Rs 75 lakhs. Since BPCL uses its own

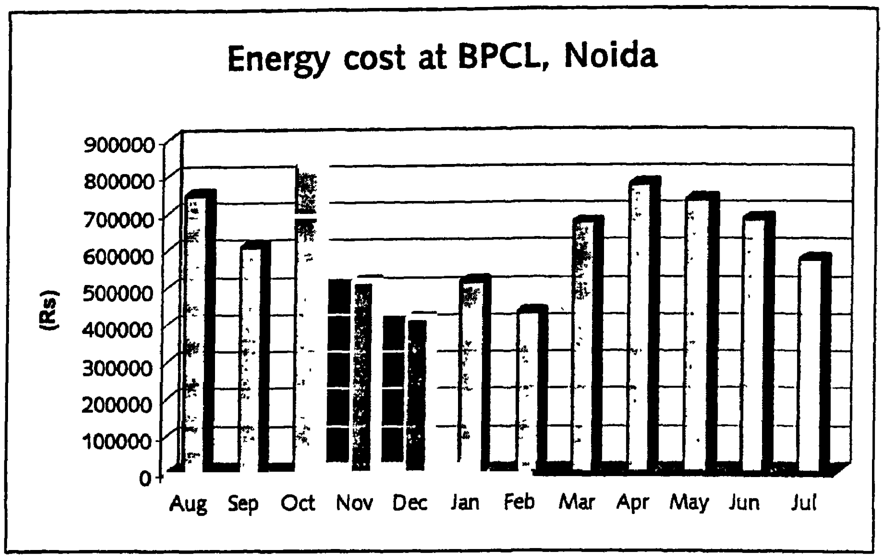

Figure 1.4

HSD the generated electricity cost is nil. However, if it has to compare with any other building the generated electricity cost at present market rate which is Rs 17/lit it comes to 11 lakhs and the total electricity cost comes to approximately Rs 86 lakhs.

Energy demand

As shown in figure 1.5 the maximum peak demand occurred in the month of July (1210 kW) which is 92% of the sanctioned demand (1318 kW).

Average peak energy demand in summer months is found to be 785 kW, and the average peak demand in winter months is 615 kW both are well below the sanctioned load.

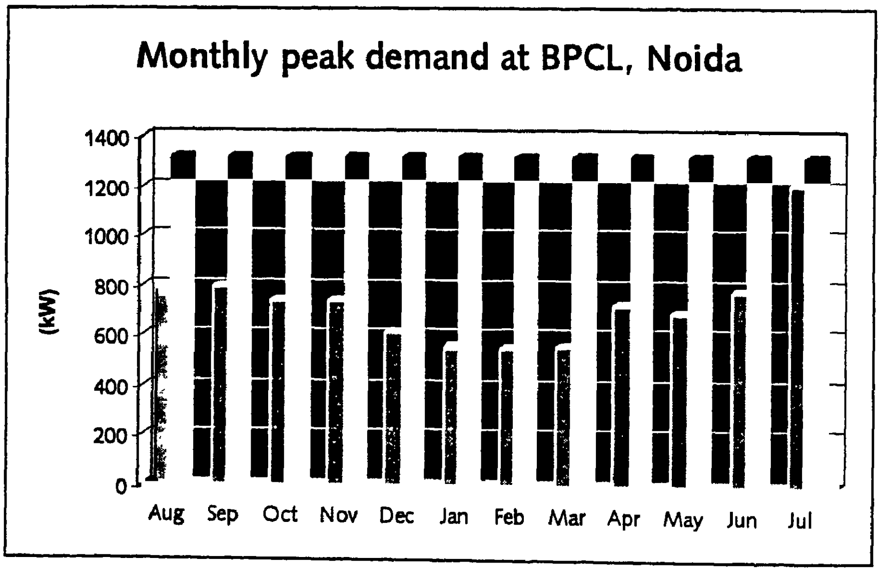

Figure 1.5

Building load on a typical summer day

During energy audit building load was monitored on the HT of the transformers. All the electrical parameters were logged at and interval of one hour from 9 AM to 5 PM. The daily load profile is shown in figure 1.6.

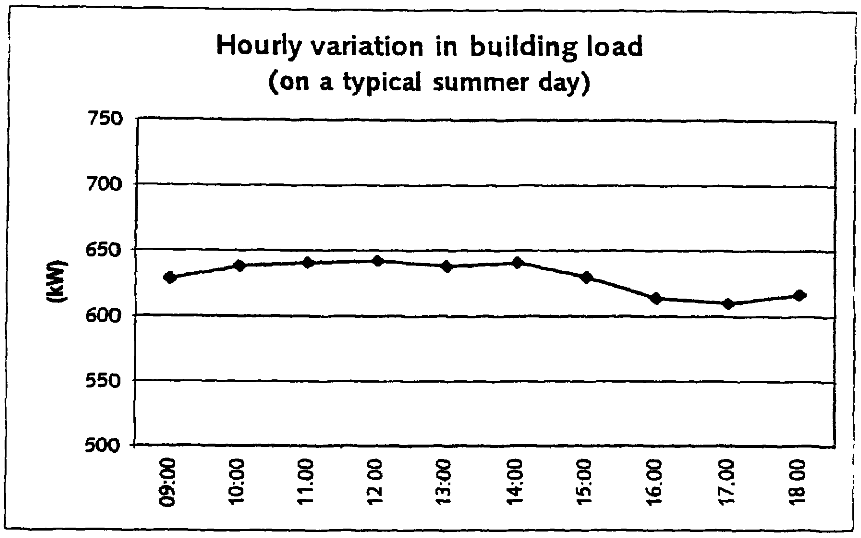

Figure 1.6

On a typical summer day the average hourly load found to be 630 kW and average consumption around 6337 kWh.

Energy performance index

The energy performance index (EPI) is developed to evaluate the building performance means whether energy being utilised efficiently in building or not. The present EPI is compared with the certain benchmark developed for similar kind of buildings in order to find out the scope in enhancement of energy performance of the building. Sometimes it is also used to compare efficiency with other buildings of similar type, nature and same climatic zone.

EPI of BPCL building which is the ratio of total annual energy use and total built up area is found to be 181 kWh/m^2. Generally an office building consuming approximately 120 kWh/m^a is considered to be an efficient building. Hence there exits a scope to reduce the consumption up to this level by appropriate energy conservation measures.

2 Electrical systems

Transformers

BPCL receives electric power from UPPCL (Uttar pradesh power corporation limited) at 11kV which is stepped down to 433V through two transformers of 1000kVA each. Electricity is billed every month based on the energy consumption during the billing period. There is no demand charges for the plant.

The electricity is charged at the rate of Rs 4.25 per kWh. The Sanctioned load of the plant is 1318 kW. The details of all the transformers installed in the plant are given in Table 2.1.

Table 2.1 Details of Transformers

S. No	Transformer	Capacity (kVA)	Voltage ratio (kV)
1.	TR-1	1000	11/0.433
2.	TR-2	1000	11/0.433

Data on hourly current reading of distribution transformers was collected for two representative days in summer and in winter to study the efficiency of the transformer at varying load conditions The designed losses of those transformers which are taken up for analysis are given in table 2.2.

Table 2.2 Losses of distribution transformers

Sno	Transformer	Capacity (kVA)	Voltage ratio (kV)	Full load losses (kW)	No load loss (kW)	Calculated load for maximum efficiency (kVA)
1	TR-1	1000	11/0.433	11.6	1.5	385
2	TR-2	1000	11/0.433	11.6	1.5	385

Table 2.2 also shows the load for which the transformers would operate at their designed maximum efficiency. These loadings have been calculated from the test certificate of transformers.

Transformer loading

Transformer audit of the plant was done with a view to provide better quality of power to different load centres at increased overall efficiency (through appropriate load on each transformer). A detailed analysis of the loading pattern of both the transformers studied is produced and given below:

The transformer No 1 and 2 are of 1000 kVA, 11/0.433 kV capacity each respectively and feed power to the different loads in the plant. Based on the voltage and current readings of these transformers for a representative day of the summer and winter months, loading and total losses for both the transformers were evaluated. Table 2.3 & 2.4 gives the loading and total losses of transformer No. 1 and 2 for a representative day for the summer month while Table 2.5 & 2.6 gives the loading and total losses of transformer No. 1 and 2 for a representative day for the winter month.

Table 2.3 Loading and losses of transformer 1

Time	Load (kVA)	Loading	losses (kW)
9	560	56%	4.67
10	560	56%	4.67
11	560	56%	4.67
12	600	60%	5.14
13	560	56%	4.67
14	560	56%	4.67
15	440	44%	3.46
16	480	48%	3.83
17	480	48%	3.83
18	400	40%	3.12

Table 2.4 Loading and losses of transformer 2

Time	Load (kVA)	Loading	losses (kW)
9	440	44%	3.46
10	400	40%	3.12
11	400	40%	3.12
12	560	56%	4.67
13	560	56%	4.67
14	560	56%	4.67
15	520	52%	4.23
16	560	56%	4.67
17	560	56%	4.67
18	520	52%	4.23

Table 2.5 Loading and losses of transformer 1

Time	Load (kVA)	Loading	losses (kW)
9	200	20%	1.90
10	320	32%	2.53
11	360	36%	2.81
12	320	32%	2.53
13	320	32%	2.53
14	320	32%	2.53
15	280	28%	2.29
16	280	28%	2.29
17	280	28%	2.29
18	280	28%	2.29

Table 2.6 Loading and losses of transformer 2

Time	Load (kVA)	Loading	losses (kW)
9	200	20%	1.90
10	320	32%	2.53
11	320	32%	2.53
12	320	32%	2.53
13	320	32%	2.53
14	320	32%	2.53
15	320	32%	2.53
16	320	32%	2.53
17	320	32%	2.53
18	280	28%	2.29

It can be seen from the table that the average loading for transformer No. 1 and 2 on the representation day of summer month was 52 percent and 50 percent of the total rated capacity respectively. While the average loading for transformer No. 1 and 2 on the representation day of winter month was 29 percent and 30 percent of the total rated capacity respectively.

It can be calculated from the test certificates that both the transformers have been designed to have peak efficiency at 38.5 percent (385 kVA) of the rated load. It can, therefore be concluded that average loading of transformers are more then the required load for maximum efficiency in summers while it is less then the load for maximum efficiency during winters. Deviation from the load required for maximum efficiency would result is decrease in efficiency levels of the transformer It is therefore recommended to continue the existing operating practice of running two transformers.

Power quality study

A study of power quality and outages was carried to assess the power supply situation and its impact on the energy performance of the plant as a whole. This based on the data of outages and tap changes maintained in the plant. Figure 2.1 gives the data of power failures while figure 2.2 gives the tap changes.

It is clear from the figures that levels of outages and poor voltages levels are higher during the summer months. The supply outages are found to be much higher then poor voltage regulation.

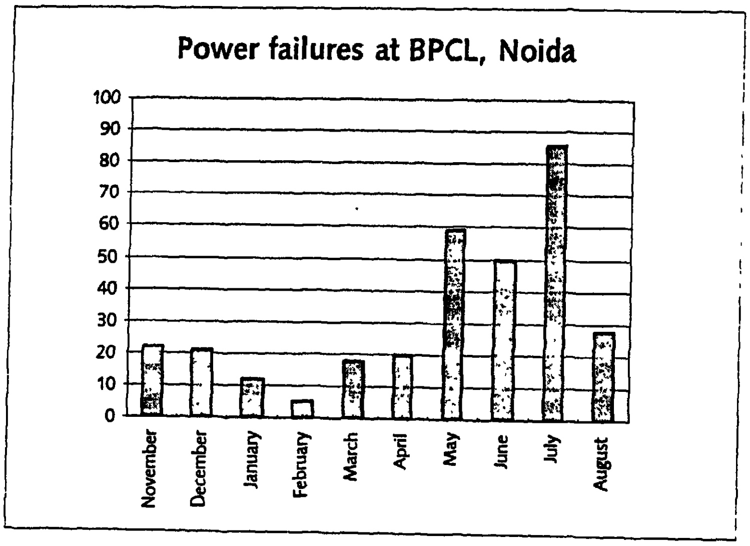

Figure 2.1

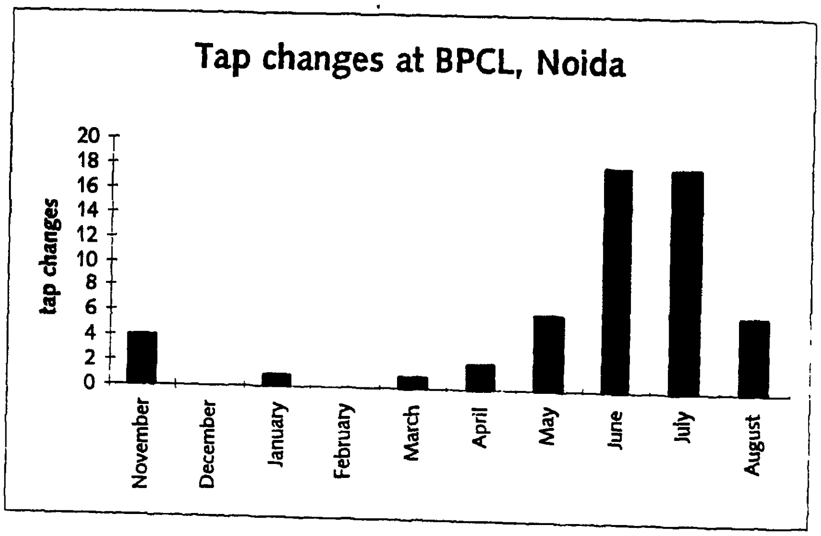

Figure 2.2

Impact of power quality on energy performance of the plant

Performance of the AC plant is affected due to poor power supply. At present the plant is operating DG sets of 750kVA in case of power outages and tap positions of the changer installed in the transformer are adjusted to maintain voltages levels in the plant. Every time there is a power outage or poor regulation in the power supply all loads in the plants are cut off from the power supply. Therefore restoration of the power supply takes time. This is particularly true for the chilling plant. It takes about 30 minutes to restart the plant and bring it on load. During this time there is an ingress of heat in the system. Therefore additional heat load is added to the AC plant resulting in higher power consumption. This problem is higher during summer months, when the frequency of power supply outages are also higher.

During period of erratic power supply, which is quite frequent in peak summers it would be beneficial to shift from grid supply to DG sets while the problem of high voltage, fluctuations of grid supply can be resolved by installing automatic voltage regulating device.

Motor load test

Measurement

Motor load test has been carried out on 23 motors at BPCL, Noida to find out their loading percentage and operating efficiency. Electrical parameters like voltage (V), current (I), power factor (PF), and input electrical energy (kW) were measured on each phase and they are listed in table 2.7.

Table 2.7 Operating electrical parameters of motors

S.No.	Name of Motor	V	I	PF	KW
1	AHU - 24	390	7.33	0.71	1.17
		393	6.95	0.71	1.12
		397	6.8	0.69	1.07
2	AHU - 12	386	6.73	0.66	0.99
		391	6.35	0.66	0.95
		390	6.36	0.67	0.96
3	AHU - 23	371	6.49	0.5	0.69
		367	5.58	0.5	0.59
		364	5.94	0.58	0.72
4	AHU - 11	369	4.59	0.64	0.63
		372	4.55	0.67	0.65

S.No.	Name of Motor	V	I	PF	KW
		376	4.78	0.68	0.7
5	AHU - 10	400	5.66	0.72	0.94
		400	5.35	0.7	0.87
		393	5.25	0.71	0.84
6	AHU - 22	398	4.89	0.66	0.74
		404	4.88	0.65	0.74
		405	5.22	0.67	0.81
7	AHU - 21	379	6.32	0.74	1.03
		385	6.4	0.72	1.03
		386	6.71	0.75	1.12
8	AHU - 9	395	5.1	0.66	0.8
		395	5.08	0.65	0.76
		391	4.92	0.64	0.71
9	AHU - 7	386	6.72	0.76	1.14
		385	6.45	0.77	1.1
		381	6.33	0.76	1.06
10	AHU - 5	376	6.51	0.85	1.2
		379	6.45	0.84	1.19
		378	6.48	0.85	1.2
11	AHU - 16	393	5.36	0.81	0.98
		395	5.03	0.81	0.92
		388	5.04	0.82	0.93
12	AHU - 4	383	3.27	0.47	0.34
		388	3.12	0.49	0.34
		383	3.16	0.48	0.34
13	AHU - 3	393	4.11	0.6	0.56
		388	3.79	0.6	0.51
		386	3.81	0.6	0.51
14	AHU - 15	381	4.18	0.52	0.48
		388	4.17	0.52	0.49
		390	4.31	0.55	0.53
15	AHU - 17	374	5.15	0.75	0.83
		376	5.33	0.74	0.86
		371	5.16	0.74	0.82
16	AHU - 18	400	5.18	0.61	0.73
		391	5	0.6	0.68
		393	4.86	0.61	0.67

S.No.	Name of Motor	V	I	PF	KW
17	AHU - 19	385	6.04	0.65	0.87
		385	5.67	0.62	0.79
		386	5.56	0.65	0.81
18	AHU - 20	398	3.77	0.64	0.56
		398	7.47	0.82	1.41
		395	7.31	0.39	0.66
19	AHU - 8	410	5.44	0.66	0.86
		410	5.27	0.66	0.83
		407	5.25	0.64	0.8
20	AHU - 6	412	5.38	0.53	0.67
		414	5.5	0.53	0.7
		421	5.79	0.52	0.74
21	Cooling Tower -1	383	10.98	0.47	1.14
		395	10.50	0.45	1.07
		398	10.65	0.46	1.12
22	Cooling Tower -2	388	11.20	0.37	0.93
		391	11.05	0.38	0.94
		391	11.30	0.38	0.98
23	Cooling Tower -3	404	10.41	0.47	1.14
		404	10.41	0.44	1.06
		397	10.08	0.44	1.03

Analysis

Based on the above data the % loading and operating efficiency of each motor has been calculated and listed in table 2.8 below.

Table 2.8 Motor loading and operating efficiency

S.No.	Name of Motor	Rated KW	Measured KW	% Loading	Operating Eff.
1	AHU - 24	7.5	3.36	39	75
2	AHU - 12	7.5	2.90	34	71
3	AHU - 23	5.5	2.00	32	70
4	AHU - 11	5.5	1.98	31	70
5	AHU - 10	5.5	2.65	42	78
6	AHU - 22	5.5	2.29	36	73
7	AHU - 21	7.5	3.18	37	73
8	AHU - 9	5.5	2.27	36	73
9	AHU - 7	7.5	3.30	38	74
10	AHU - 5	7.5	3.59	42	78
11	AHU - 16	5.5	2.83	45	80

S.No.	Name of Motor	Rated KW	Measured KW	% Loading	Operating Eff.
12	AHU - 4	3.7	1.02	23	50
13	AHU - 3	3.7	1.58	36	65
14	AHU - 15	3.7	1.50	34	64
15	AHU - 17	5.5	2.51	40	72
16	AHU - 18	5.5	2.08	33	72
17	AHU - 19	3.7	2.47	56	79
18	AHU - 20	5.5	2.63	42	78
19	AHU - 8	5.5	2.49	39	74
20	AHU - 6	5.5	2.11	33	72
21	Cooling Tower-1	7.5	3.33	39	75
22	Cooling Tower-2	7.5	2.85	33	70
23	Cooling Tower-3	7.5	3.23	37	73

Observations and Recommendations

- Motor loading percentage varies from as low as 23 % (AHU-4) to go as high as 56% (AHU-19).
- Out of 23 motors, loading of 6 motors lies in the range of 40 to 80%, and 17 motors are loaded below 40%.
- The power factor of fan motors lies between 0.39 to 0.85.
- The supply voltage during measurement has been observed fluctuating between 364 to 421.
- There is no need to replace the under loaded motors with lower rating motors as the operating efficiencies of all the AHUs motors are more than 60%. Furthermore few motors ratings are less than 5 hp. Our experience shows that the replacement of motors of less than 5 hp motors even if they are operating at less than 40% loading with lower sized motors does not yield any energy savings.

Power factor

The line current drawn by Induction motors, transformers and other inductive devices consists of two components; the magnetizing current and the power producing current. The magnetizing current is required to produce the magnetic flux in the machine. This component of current creates a reactive power compensation, which is measured in kilo-volt amperes reactive (kVAR). The power producing current is that current which reacts with the magnetic flux to produce the output torque of the machine. This component of current creates the load power requirements measured in kilowatts (kW). The magnetizing current and magnetic flux are relatively constant at constant voltage. However the power producing current is proportional to the load torque requirements. The magnetizing current is essential for transferring power through the core of the transformer or across the air gap of an induction motor. The magnetizing current lags the voltage by 90 degree. The total current drawn by the machine is the vector sum of this reactive current and the power producing current. The power factor is defined as the cosine of the angle between total current and power producing current vectors.

Low power factor leads to poor system efficiency as the high reactive component associated with low power factor gives rise to additional losses through out the system. An improvement in the power factor leads to

- Reduction of load on transformer and distribution equipment.
- Reduction of load losses in transformers, distribution cables and other equipment resulting in a direct savings of kWh power consumption
- Stabilization of the system voltage

Present power factor scenario

To analyse the present power factor scenario of the building, monthly data of average power factor was collected from the electricity bills for a period starting from August'01 to August'02. Table 2.9 gives the power factor and maximum demand during the period. The variation of monthly power factor for the above period is shown in Figure 2.1. It could be observed from the figure 2.1 that the average monthly power factor of the building varied from 0.79 to 0.86. The variation in power factor is due to non-operation of AC loads during winter season.

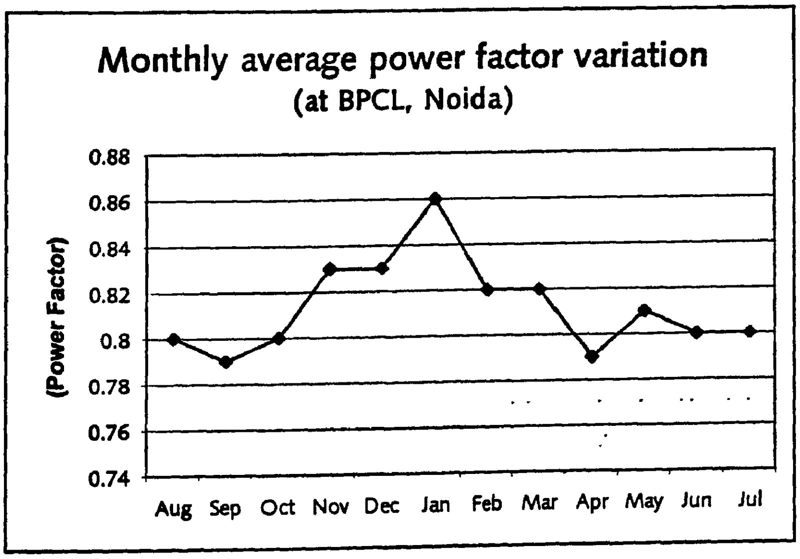

Figure 2.3

Table 2.9 Monthly average power factor of the building

S.No.	Month	Present Power Factor	Recorded Max. Demand (kVA)	Desired power factor	Capacitor size (kVAR)
1	August'01	0.80	938	0.95	316
2	September'01	0.79	1004		354
3	October'01	0.80	922		310
4	November'01	0.83	890		253
5	December'01	0.83	738		210
6	January'02	0.86	646		147
7	February'02	0.82	676		204
8	March'02	0.82	680		205
9	April'02	0.79	894		315
10	May'02	0.81	854		273
11	June'02	0.80	972		327
12	July'02	0.80	1512		509
13	August'02	0.79	998		352

A compensation scheme has been devised by BPCL to improve the overall power factor by installing capacitor banks at the sub-station. The installed capacity of such capacitors is given in Table 2.10. Further, automatic power factor correction relay has also been installed at the sub-station but it was found to be out of order during the audit study.

Table 2.10 Details of capacitors installed

S.No.	Location	Capacity (kVAR)	Number	Total (kVAR)
1.	Main bus-bar no.1	25	8	200
2.	Main bus-bar no.2	25	8	200
	Total			400

As per the tariff structure, BPCL does not have to pay any demand charges and there is no penalty clause if the average power factor drops below 0.85. However, in near future distribution companies would very likely impose low power factor penalty for various consumers, as the capacity of the existing distribution system would be stressed with increasing consumer load. Moreover, the improvement in power factor of various consumers would also lead to reduction in distribution losses of the distribution companies. It is, therefore, recommended that power factor of the building be maintained at 0.95 power factor while drawing power from Uttar Pradesh Power Corporation Limited (UPPCL). Additionally, the improvement in power factor will also lead to a reduction in transformer loading, resulting in savings in transformer load losses and thus reduction in power consumption.

Power factor measurements

Power factor measurements were carried out to evaluate the performance of the existing reactive power compensation scheme and suggest improvements.

The condition of all installed capacitor banks was checked to know the exact kVAR being supplied by these capacitors in the system. It was found that all the capacitor banks were not in working condition. It is, therefore, recommended to replace all faulty capacitor banks with new ones.

Compensation Scheme

Since the load on main bus-bars does not vary frequently, automatic power factor correction relay installed on main bus-bars is appropriate to maintain a high power factor. This type of relay operating in `auto' mode senses the load, voltage and current of the connected system and automatically controls switching of capacitors from the bank, thus delivering a high power factor (at a pre-set value) at all loads. Therefore, the existing centralized location and automatic switching of capacitors of the banks, is well suited for the type of the power distribution system.

To achieve a power factor value of 0.95, which is considered to be a reasonable figure, the required size of capacitors has been worked out for past 13 months and presented in Table 2.9. It can be seen from the table that there is no need to augment the rated capacity of installed capacitor banks of 400 kVAR to maintain a power factor of 0.95.

3

Lighting systems

Lighting systems in fully air-conditioned office consume energy only next to HVAC systems and also contribute substantial to the total connected load. Visual effects created by installed lighting schemes are always a very important factor in office lighting design. Generally psychological and esthetical impacts get upper hand in selection of lighting schemes and that makes the lighting systems inefficient. But growing concern about energy wastage has matured people enough to design, operate and maintain lighting systems efficiently. Considering this in mind a detailed technical survey of the lighting systems installed at BPCL has been conducted and various survey details are given in sections below.

Lighting systems connected load

The connected lighting system loads at present the BPCL building is approximately 181 kW or 18 W/m² however, the design connected load (as given in the drawings) was 278 kW or 27 W/m². Floor-wise break-up of connected lighting load is given in table below.

Table 3.1 Floor-wise connected lighting load

S No.	Area	Connected lighting load (kW)
1	Basement	12.88
2	Ground Floor	32.84
3	First Floor	15.44
4	Second Floor	12.96
5	Third Floor	17.88
6	Fourth Floor	12.18
7	Fifth Floor	12.71
8	Sixth Floor	14.06
9	Seventh Floor	15.55
10	Eighth Floor	12.62
11	Ninth Floor	11.75
12	External Area	10.24

As evident from table above between the floors the maximum connected lighting load on the ground floor and the minimum on ninth floor. However, basement and external lighting loads are less than individual floor loads.

Existing lighting schemes

Lamps

The indoor illumination in BPCL building is provided predominantly with the help of fluorescent lamps however 12-V miniature halogens are also used in large proportion. Compact fluorescent lamps are also used specially in corridors and lift lobbies and toilets. For external lighting, metal halide lamps are used as chief lighting source however, high-pressure sodium lamps popularly known as SON are used for façade and security lighting. One good thing has been observed that the negligible use of inefficient incandescent lamps. The lamp type used, their number and light load contributed by them are given in table3.2 below.

Table 3.2 Types of lamps used

S No.	Lamp type	Number	Lighting load (kW)
1	Compact fluorescent lamps	888	7.11
2	Incandescent lamps	8	0.52
3	Fluorescent lamps	2263	116.90
4	12-V miniature halogens	853	42.65
5	Metal halide	62	9.92
6	High pressure sodium	14	3.92

Lamp characteristics

Lamp selection for any lighting schemes depends on mainly three lamp characteristics, luminous efficacy, light colour and its colour rendition. Luminous efficacy is the ratio of light out put to the lamp wattage and it's a measure of lamp efficiency. Its colour-correlated temperature (CCT) defines the light colour of a lamp and measured in Kelvin. Lower values show yellow colour and high white colour. The ability of a lamp to help identify true colour of an object is defined as its colour rendition index (CRI). A perfect CRI (100) means that a lamp's light is identical to daylight in colour quality. These three characteristics of various lamps, which are used in BPCL, are given below.

Table 3.3 Characteristics of light sources

Lamp type	Luminous efficacy (lm/W)	CCT (K)	CRI
Incandescent	11-19	2700	100
12-V halogens	18	3000	100
Fluorescent 40W	62.5	4300-6500	60-85
Fluorescent 36 W	68	4300-6500	60-85
Fluorescent-trulite	90	2700-6500	85
Fluorescent T-5	100	2700-6500	85
Compact fluorescent lamps	65-98	2700-6000	85
Metal Halide	65-120	2900-6000	60-93
High pressure mercury	65-110	2200-2500	20-65

As shown in figure 3.1 below, TL accounts for 65% of the connected lighting load followed by halogens, which contribute 24% to the total load. Metal halide and CFL share 5% and 4% respectively and remaining 2% is of High-pressure sodium lamps load.

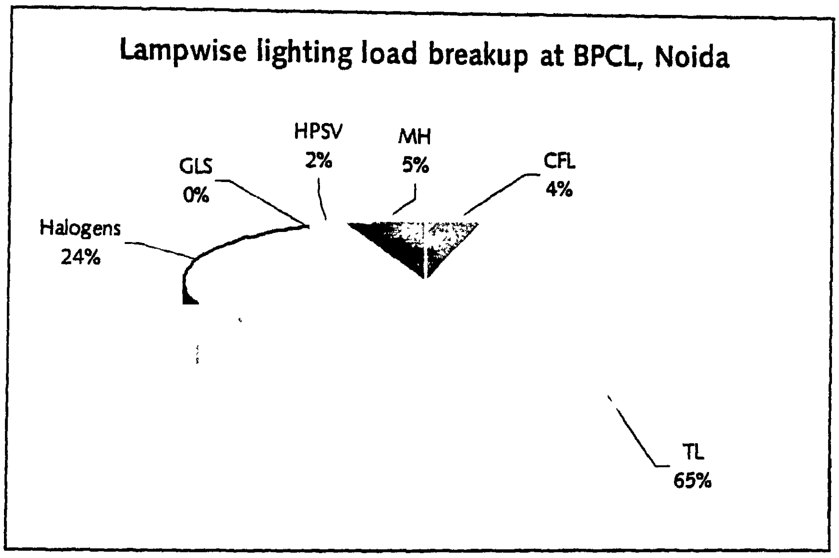

Figure 3.1

Lighting systems consumption pattern

At the BPCL, separate energy meters have not been installed to record the consumption in lighting systems in different areas. However, based on operating schedules of lighting systems and operating and connected load, the energy consumed in lighting system has been estimated. The operating lighting load, hours of operation, and energy used in lighting systems are given in table below.

Table 3.4 Energy use in lighting systems

S No	Area	Opt. Load (kW)	Operating hours per day	Max. consumption on a typical day (kWh)
1	Basement	12.88	14	180
2	Ground Floor	32.84	14	460
3	First Floor	15.44	14	216
4	Second Floor	12.96	14	181
5	Third Floor	17.88	14	250
6	Fourth Floor	12.18	14	171
7	Fifth Floor	12.71	14	178
8	Sixth Floor	14.06	14	197
9	Seventh Floor	15.55	14	218
10	Eighth Floor	12.62	14	177
11	Ninth Floor	11.75	14	165
12	External Area	10.24	14	143

The maximum daily consumption in lighting systems is estimated to be approximately 2535 kWh, which is around 29% of the total energy consumption on a typical summer day.

Measured and recommended illumination levels

Lighting levels in almost each area of BPCL were measured with the help of a digital lux meter. Since light quantity (lighting levels) and light quality are two basic components of design of any lighting schemes and together they reflect how well light a scheme is designed and whether it gives the required visual comfort to the occupant or not. Lighting schemas designed for excessive light levels waste tremendous amount of energy and they need some special attention to improve their efficiency however a light quantity less than the recommended value also adds to the visual discomfort.

Table 3.5 Recommended lighting levels

S No.	Location	Lighting levels (Lux)
1	Public spaces with dark surroundings	30
2	Corridors, inactive storage areas, dining areas	75
3	Office lobby, elevators, stairs, washrooms, active storage	150
4	Conference rooms, general office, cashier	300
5	Office desk areas, machine shop, kitchen	500
6	Drafting rooms	750

Table 3.6 Measured lighting levels at various locations

S No.	Area	Measured lighting levels (lux)
Ground Floor		
1	Fire control room	100
2	Drivers' room	100
3	Mail section	130
4	Corridor	10
5	Reception	180
6	Exhibition hall	15
7	Library	120 to 175
First Floor		
1	Senior Manager (HRD) cabin	80
2	DGM (Lubricant) cabin	180
3	Logistics Officer cabin-1	180
	Logistics Officer cabin-2	80
	A K Dutta cabin	180
	Chief Manager cabin	110
	B S Prasad cabin	110
	R G Misra cabin	140
Second Floor		
1	Engineering & Projects	120 to 200
2	GM (E&P) cabin	150
Third Floor		
1	Retail (South)	100 to 180
2	DGM (Retails) cabin	180

S No.	Area	Measured lighting levels (lux)
3	Retail (North)	160 to 200
Fourth Floor		
1	Aviation (North) cabin	200
2	Cabin	150
3	Cabin	170
4	Team Leader (HR) cabin	200
5	Marketing Manager (HR) cabin	180
Fifth Floor		
1	North-HRS	80 to 130
2	DGM (P) cabin	135
3	Manager (Admin) cabin	180
4	Senior Manager (Benefit) cabin	170
5	Manager cabin	160
6	South-admin	120 to 140
7	Senior Manager cabin	160
8	Manager cabin	180
Sixth Floor		
1	South Information System Services	100 to 150
2	Manager (EDP) cabin	180
3	Server room	110
	South cash department	130 to 160
Seventh Floor		
1	North legal department	100 to 140
2	Chief Manager (Legal) cabin	180
3	Regional LPG co-ordinator cabin	160
4	South LPG	80 to 160
5	DGM- LPG cabin	280
Eighth Floor		
1	Logistics North	120 to 140
2	Chief operations manager cabin	180
3	Senior distribution manager cabin	160
Ninth Floor		
1	Tables near materials dept.	120 to 150
2	DGM E&P cabin	200
3	Engineering Dept.	120 to 140
4	Senior materials manager cabin	90

- Lighting levels in open plan office areas are less as compared to the cabins however, at both the places they are slightly less than the recommended illumination levels.

Energy conservation options

Measure-1: Replace copper chokes with electronic chokes in fluorescent fixtures

In normal copper choke the power loss is around 15 Watt. A single TL assembly fitted with 40 W or 36 W lamp and copper choke operates at 55 W or 51 W. In electronic choke the power loss is almost negligible (1 to3 Watt) and there exists a potential to save approximately 13 Watt in each tube light fixture with electronic choke.

Table 3.7 Energy saving potential due to electronic choke in TL fixtures

Lamp type	Lamp W	(Lamp+copper choke) W	No. of lamps	(Lamp+electronic choke) W	KW saved	Opt. Hrs/day	No. of days/yr	Energy saved (kWh)/yr
TL	20	35	14	23	0.168	14	275	647
TL	36	51	1822	39	21.864	14	275	84176
TL	40	55	427	43	5.124	14	275	19727

Table 3.8 Cost benefit analysis

Lamp type	Lamp W	No. of lamps	Energy saved (kWh)/yr	Energy cost saved (Rs)/yr*	Initial Investment (Rs)**	Simple Payback (yr)
TL	20	14	647	2781	5600	2.0
TL	36	1822	84176	361959	728800	2.0
TL	40	427	19727	84828	170800	2.0

* Electricity rate : Rs 4.30/kWh

**Cost of electronic chokes : Rs 400/choke

Total energy saving potential : 104551 kWh/yr

Total saving in energy cost : Rs 449570/yr

Initial invest required
(@ of Rs 400/electronic choke) : Rs 905200

Simple payback : 2 years

Option-2: Replace all the existing 40 W & 36 W TL with energy efficient T-5 fluorescent tubes

Majority of the existing installation in BPCL building are with T-12 (40 W) & T-8 (36 W) fluorescent lamps with magnetic choke (with average watt loss of 15 watts). The existing fluorescent tubes can be easily replaced by T-5 retrofit system consisting of FH28W lamp with electronic ballast with less than 2W loss i.e. a total of 30 watts resulting in a saving of 25 watts per 40W-tube replacement and 21 watts in 36 W-tube.

Table 3.9 Energy saving potential due to T-5 lamps

Lamp type	Lamp W	(Lamp+copper choke) W	No. of lamps	(Lamp+electronic choke) W	kW saved	Opt. Hrs/day	No. of days/yr	Energy saved (kWh)/yr
TL	36	51	1822	30	38.26	14	275	147309
TL	40	55	427	30	10.68	14	275	41099

Table 3.10 Cost benefit analysis

Lamp type	Lamp W	No. of lamps	Energy saved (kWh)/yr	Energy cost saved (Rs)/yr*	Initial Investment (Rs)**	Simple Payback (yr)
TL	36	1822	147309	633427	1229850	1.9
TL	40	427	41099	176725	288225	1.6

* Electricity rate : Rs 4.30/kWh

**Cost of T-5 lamps : Rs 675/tube

Total energy saving potential	:	188407 kWh/yr
Total saving in energy cost	:	Rs 810150/yr
Initial invest required (@ of Rs 675/T-5 tube)	:	Rs 1518075
Simple payback	:	1.9 years

Option3: Replace low voltage halogen lamps (12-V 50 W) with CFLs in appropriate fixtures

Low voltage halogen lamps are very small lamps and they are capable of producing highly directable light beams. They are referred to use as focus light for highlighting decorative objects. But in BPCL building it has been observed that they are mainly used as decorative lights themselves. Since these lamps use 50 W and same king of light effects can be produced if energy efficient CFLs fitted in special type of fixtures are used. These fixtures use specially designed reflectors for producing directional beam of light and being manufactured by almost all-leading fixture manufacturers in India. Hence it is recommended to replace 12-V 50 W halogens with 9 W CFL fitted in specially designed fixtures for producing directional light.

Table 3.11 Energy saving potential due to CFL lamps in place of low voltage halogens

Lamp type	Lamp W	No. of lamps	CFL wattage	KW saved	Opt. Hrs/day	No. of days/yr	Energy saved (kWh)/yr
Low voltage halogens	50 W	853	9 W	34.943	14	275	134646

Table 3.12 Cost benefit analysis

Lamp type	Lamp W	No. of lamps	Energy saved (kWh)/yr	Energy cost saved (Rs)/yr*	Initial Investment (Rs)**	Simple Payback (yr)
Low voltage halogens	50 W	853	134646	578978	853000	1.5

* Electricity rate : Rs 4.30/kWh
**Cost of CFL lamp/Fixture : Rs 1000/lamp with fixture

Total energy saving potential	:	134646 kWh/yr
Total saving in energy cost	:	Rs 578980/yr
Initial invest required (@ of Rs 1000/lamp-fixture)	:	Rs 853000
Simple payback	:	1.5 years

Energy saving potential in lighting systems

- The lighting scheme in BPCL building was designed for a load of 278 kW with maximum consumption of 1070300 kWh per year.
- By replacing all the incandescent lamps with compact fluorescent lamps lighting load can be reduced to 181 kW (a reduction of 98 kW) and the maximum consumption would be reduced to 696850 kWh per year (a reduction of 373450 kWh).
- Replacement of T-12 & T-8 tube lights with T-5 lamps would reduce lighting load to 132 kW and the estimated maximum consumption would be 508431 kWh per year.
- Replacement of low voltage halogens with 9 W CFL in specially designed fixtures would reduce lighting load to 97 kW and the estimated maximum consumption would be 373450 kWh per year.
- With all conservation efforts lighting load can be reduced from 278 kW to 97 kW and the maximum consumption would be reduced to 373450 kWh per year from 1070300 kWh per year. Hence, in lighting system there exists a saving potential of 65% per year.

4

HVAC systems

The space conditioning in BPCL building is provided with the help of three centrally air-conditioned plant in conditioned areas that include reception, lobby, auditorium, lift lobbies and offices. However, in non-conditioned areas such as kitchens, toilets and basements thermal comfort is achieved through ventilation systems. The total connected HVAC system load is approximately 768 kW or 75 W/m^2 and accounts for 66 % of the total connected load.

AC system details

The total cooling capacity of the central AC plant is 600 TR. The central plant consists of three 200-TR Voltas centrifugal chillers. The chilled water is being circulated in chilled water line with the help of four 40-hp pumps. The warm water in condenser line is circulated with the help of four 40-hp pumps. Three induced-draft cross flow cooling towers of 250 TR capacity with fan motor of 10-hp are installed to cool warm water coming from plants' condensers.

Approximately twenty-five air-handling units (AHUs) of varying capacity and around 26 fan coil units (FCUs) are installed to provide required air-conditioning in the various areas.

AC system connected load pattern

The connected AC system load at BPCL is approximately 768 kW. In installed AC load compressors contribute to the maximum load (369 kW), chilled water pumps account for 120 kW, condenser water pumps for 120 kW, cooling towers for 22.5 kW, air handling units for 134.5 kW, and remaining 1.95 kW is fan coil units load.

The AC load density index, which is defined as total connected AC load per unit total built-up area, is found to be 75 W/m^2.

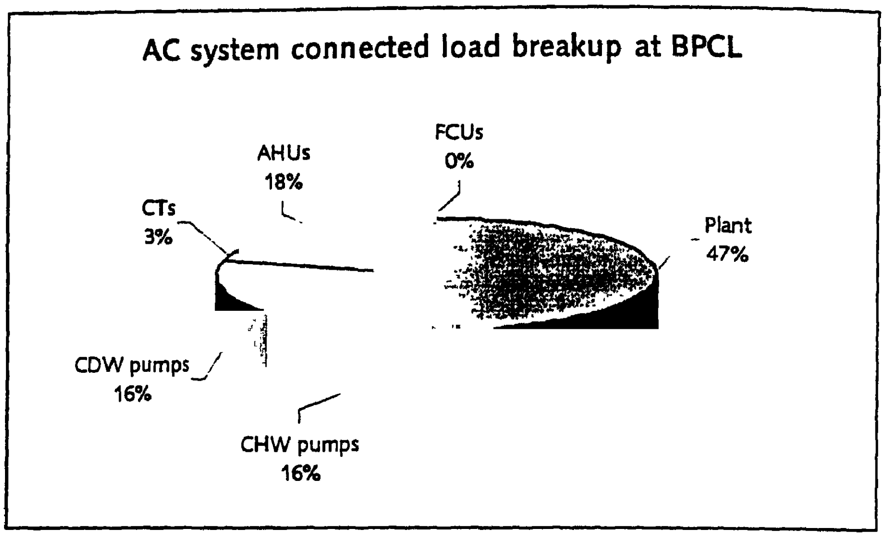

Figure 4.1

AC system consumption pattern

At BPCL, separate energy meters have not been installed to record the consumption in AC system equipment. Based on recorded log book data, measured operating efficiencies of different equipment measured during field survey, and discussion made with the engineering and maintenance staff the energy consumed in AC system has been estimated. The average operating input energy and hours of operation used in estimating the energy consumption is given in the Table 4.1 below.

Table 4.1 Operating AC equipment in March, April, September, October & November

Equipment	Average operating kW	Operating hours	Energy Consumption kWh
Plants	191	1312.5	250688
CHW pumps	63	1312.5	82688
CDW pumps	50	1312.5	65625
Cooling Towers	9.41	1312.5	12351
AHUs	58.15	1312.5	76322
FCUs	1.82	1312.5	2389

Table 4.2 Operating AC equipment in May, June, July & August

Equipment	Average operating kW	Operating hours	Energy Consumption kWh
Voltas Plants	283	1050	297150
CHW Pumps	63	1050	66150
CDW pumps	50	1050	52500
Cooling Towers	9.41	1050	9881
Air Handling Units (AHUs)	58.15	1050	61058
Fan Coil Units (FCUs)	1.82	1050	1911

The AC system being the largest load centre at BPCL is accounting for the major electricity consumption. The estimated AC system consumption is approximately 978710 kWh per year, which is around 52.5% of the total electricity consumption at BPCL. Within AC system, Plants consume maximum energy (547838 kWh), CHW pumps and CDW pumps account for 148838 kWh and 118125 kWh while the AHUs and CTs consume 137379 kWh and 22231 kWh and remaining 4300 kWh is used in FCUs.

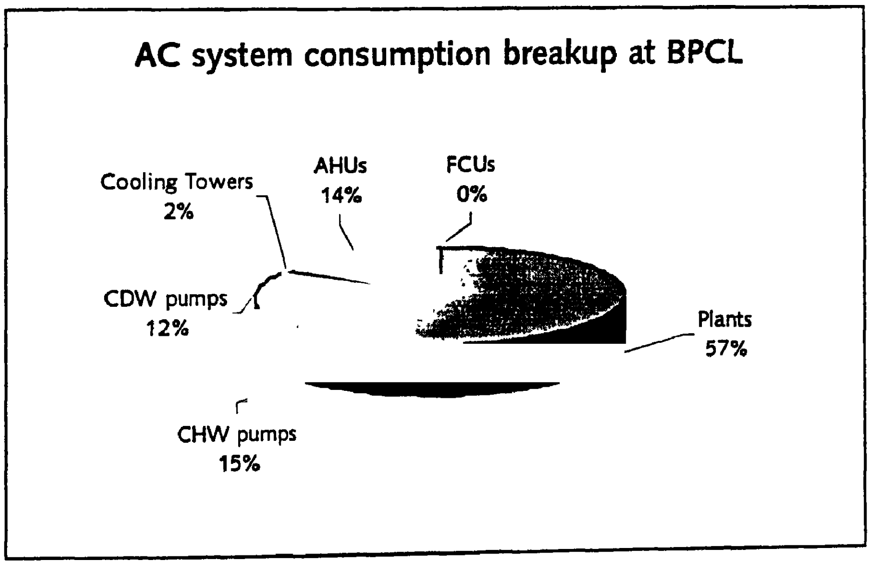

Figure 4.2

The AC consumption index, which is defined as total annual AC consumption per unit total built-up area, is found to be 95 kWh/m^2.

Observations and Measurements

Chilling Plants

The operating parameters of Plant No-1, NO-2 and NO-3 chilling plants have been monitored each for one day. The supply chilled water temperature (SCHWT), return chilled water temperature (RCHWT), entering condenser water temperature (ECDWT) and leaving condenser water temperature (LCDWT) were recorded in a data logger at 15 minutes interval. Similarly operating electrical parameters of compressors mainly voltage, current, power factor and kW were also logged for the same time when temperature data were logged. Later these data were down loaded on the computer with the help of specific software for carrying out the average operating specific power (kW/TR) of the plants.

The chilled water and condenser water flows were measured with the help of non-intrusive type flow meter near the chilled water and condenser water pumps. Based on the operating data collected, the specific power and the coefficient of performance of both the plants at operating load have been calculated. The complete details of chiller performance analysis are summarised in Tables below.

Chilling Plant No.1

Table 4.3 Operating specific power of Plant No.1

DATE	TIME	CHWT in (°F)	CHWT out (°F)	Delta T (°F)	CHW flow (gpm)	Cooling produced (TR)	Input compressor power (kW)	Operating plant efficiency (kW/TR)
07/08/2002	11:15:00	60.3	53.8	6.5	598	161	102	0.633
07/08/2002	11:30:00	58.1	52.3	5.8	598	144	101	0.702
07/08/2002	11:45:00	57.3	51.6	5.8	598	144	95	0.659
07/08/2002	12:00:00	57.6	51.7	5.9	598	147	98	0.665
07/08/2002	12:15:00	57.5	51.6	6.0	598	149	98	0.659
07/08/2002	12:30:00	57.3	51.4	5.9	598	148	100	0.677
07/08/2002	12:45:00	57.2	51.5	5.8	598	143	98	0.683
07/08/2002	13:00:00	57.0	51.2	5.8	598	145	95	0.655
07/08/2002	13:15:00	56.7	50.7	6.0	598	150	96	0.642
07/08/2002	13:30:00	56.6	51.0	5.6	598	140	98	0.701
07/08/2002	13:45:00	58.2	55.6	2.6	598	64	42	0.658
07/08/2002	14:00:00	57.3	54.5	2.8	598	69	49	0.706
07/08/2002	14:30:00	59.8	55.0	4.8	598	119	101	0.850
07/08/2002	14:45:00	62.7	58.1	4.6	598	115	74	0.646

DATE	TIME	CHWT in (°F)	CHWT out (°F)	Delta T (°F)	CHW flow (gpm)	Cooling produced (TR)	Input compressor power (kW)	Operating plant efficiency (kW/TR)
07/08/2002	15:00:00	59.2	52.7	6.5	598	161	84	0.520
07/08/2002	15:15:00	59.0	52.5	6.5	598	162	105	0.649
07/08/2002	15:30:00	58.7	52.2	6.5	598	161	108	0.672
07/08/2002	15:45:00	58.5	52.0	6.5	598	161	106	0.657

The average operating efficiency of the plant no-1 is found to be 0.669 kW/TR that means in order to produce one TR of cooling the plant input energy is 0.669 kW. The rated efficiency of the plant is 0.615 kW/TR at full load which indicates that the operating efficiency is slightly lower as compared to the rated one or in other words this plant is taking 0.054 kW extra for producing each TR of cooling.

Chilling Plant No.2

Table 4.4 Operating specific power of Plant No.2

DATE	TIME	CHWT in (°F)	CHWT out (°F)	Delta T (°F)	CHW flow (gpm)	Cooling produced (TR)	Input compressor power (kW)	Operating plant efficiency (kW/TR)
06/08/2002	11:00:00	57.2	53.6	3.6	598	89	82	0.919
06/08/2002	11:15:00	57.3	53.6	3.6	598	91	87	0.959
06/08/2002	11:30:00	56.3	52.3	4.0	598	100	85	0.848
06/08/2002	11:45:00	55.5	51.7	3.9	598	97	89	0.917
06/08/2002	12:00:00	56.4	52.5	3.9	598	96	93	0.969
06/08/2002	12:15:00	56.3	52.3	4.0	598	99	92	0.927
06/08/2002	12:30:00	56.1	52.2	3.9	598	97	89	0.921
06/08/2002	12:45:00	56.1	52.3	3.8	598	94	89	0.944
06/08/2002	13:00:00	56.0	52.2	3.8	598	95	91	0.962

The average operating efficiency of the plant no-2 is found to be 0.930 kW/TR that means in order to produce one TR of cooling the plant input energy is 0.930 kW. The rated efficiency of the plant is 0.615 kW/TR at full load, which indicates that the operating efficiency is very low as compared to the rated one or in other words this plant is taking 0.315 kW extra for producing each TR of cooling.

Chilling Plant No.3

Table 4.5 Operating specific power of Plant No.3

DATE	TIME	CHWT in (°F)	CHWT out (°F)	Delta T (°F)	CHW flow (gpm)	Cooling produced (TR)	Input compressor power (kW)	Operating plant efficiency (kW/TR)
05/08/2002	12:30:00	61.2	57.4	3.8	598	96	111	1.161
05/08/2002	13:00:00	60.2	56.1	4.1	598	101	104	1.027

DATE	TIME	CHWT in (°F)	CHWT out (°F)	Delta T (°F)	CHW flow (gpm)	Cooling produced (TR)	Input compressor power (kW)	Operating plant efficiency (kW/TR)
05/08/2002	13:30:00	58.8	55.2	3.5	598	88	102	1.158
05/08/2002	14:00:00	58.0	54.5	3.5	598	87	98	1.132
05/08/2002	14:30:00	57.4	54.0	3.4	598	84	98	1.170
05/08/2002	15:00:00	56.3	53.1	3.2	598	81	100	1.235
05/08/2002	15:30:00	55.7	52.6	3.1	598	77	100	1.304
05/08/2002	16:00:00	54.7	51.9	2.8	598	70	100	1.428
05/08/2002	16:30:00	54.6	51.3	3.4	598	84	100	1.190

The average operating efficiency of the plant no-3 is found to be 1.201 kW/TR that means in order to produce one TR of cooling the plant input energy is 1.201 kW. The rated efficiency of the plant is 0.615 kW/TR at full load, which is almost half of the operating efficiency.

The operating and rated specific power consumption of each plant is given below.

Table 4.6 Operating & rated plant efficiencies

Plant No	Average operating specific power (kW/TR)	Rated specific power at full load (kW/TR)
Plant No-1	0.669	0.615
Plant No-2	0.930	0.615
Plant No-3	1.201	0.615
Average plant	0.933	0.615

The average plant operating efficiency is 0.933 kW/TR as compared to the rated efficiency of 0.615 kW/TR that means for producing one ton of cooling chillers are consuming 0.318 kW more than what they are supposed to consume as per design considerations.

The minimum and maximum supply chilled water temperatures plants are as follows.

Table 4.7 Minimum & maximum supply chilled water temperatures

Plant No	Minimum supply CHWT (° F)	Maximum Supply CHWT (° F)
Plant No-1	50.7	57.6
Plant No-2	51.7	53.6
Plant No-3	51.3	57.4

As evident from the above table the minimum supply temperatures are always remained above the rated supply chilled water temperature of 44 ° F that might lead to high humidity in the rooms during monsoon period.

The average difference of CHW return temperature and CHW supply temperature for each plant has been observed as follows:

Table 4.8 Chilled water temperature difference maintained by plants

Plant No	Operating chilled water difference (° F)	Rated CHW temperature difference (° F)
Plant No-1	6.1	10
Plant No-2	3.8	10
Plant No-3	3.4	10

The operating difference is around 4.4 ° F as against the design 10 ° F this shows that the system is not being operated to utilise the full plant capacity or the chilled water flow through plant is more than the rated flow.

The average entering condenser water temperature in each plant is given below:

Table 4.9 Entering condenser water temperatures in various plants

Plant No	Operating entering condenser water temperature (° F)	Design entering condenser water temperature (° F)
Plant No-1	86.9	90
Plant No-2	86.7	90
Plant No-3	88.3	90

The average entering condenser water temperature in operating condition is around 87.3 ° F as against the design 90 ° F this indicates unnecessary cooling at cooling towers.

CHW pumps and CDW pumps

The measured operating parameters of the CHW pumps and CDW pumps and complete analysis of pump performance evaluation are given in table 4.4 and table 4.5. The operating heads of CHW pumps and CDW pumps were measured with the help of digital pressure differential meters. Operating pump motor input was also measured with the help of power multi-meter. Flows were measured with the help of a non-intrusive type flow meter.

Chilled water pumps

Table 4.10 Operating efficiencies of CHW pumps

Pump	Dis. P	Suc. P	Head "ft"	Input motor kW	Pump BHP	Water flow rate	Efficiency (%)
CHW pump no-1	112	72	92.28	20.3	24.36	599	57.3
CHW pump no-3	112	72	92.28	21.2	25.44	597	54.7
CHW pump no-4	112	72	92.28	21.5	25.8	598	54.0

Table4.11 Rated and operating parameters of CHW pumps

	Rated condition	Operating condition
Head (Ft of W)	120	92.28
Capacity (USgpm)	600	598
Pump input kW	23.49	20.1
Pump efficiency (%)	78	55.3

The average operating pump efficiency of 40 hp CHW pumps is approximately 55.3% which is less as compared to rated efficiency of 75 to 80% of the new generation energy efficient pumps.

The 40-hp pumps are delivering an average 598 gpm per pump at 92.3' head, which is almost same as rated flow.

Condenser water pumps

Table 4.12 Operating efficiencies of CDW pumps

Pump	Discharge pressure (psi)	Suction pressure (psi)	Head "ft"	Input motor kW	Pump BHP	Water flow rate	Efficiency (%)
CDW pump no-2	108	65	99.201	25.2	30.24	634	52.5
CDW pump no-3	108	65	99.201	24.8	29.76	631	53.1

Table4.13 Rated and operating parameters of CDW pumps

	Rated condition	Operating condition
Head (Ft of W)	105	99.2
Capacity (USgpm)	800	633
Pump input kW	27.22	22.5
Pump efficiency (%)	77	52.8

The CDW pumps are operating at an average efficiency of 52.8% as compared to rated efficiency of 75 to 80% of new generation pumps that is extremely low.

The CDW pumps are delivering a discharge of 634 gpm/pump at 99.2' head as compared to the rated flow of 600 gpm at 120' head.

Cooling tower performance analysis

Different measurements taken on the cooling towers are given in Table 4.6. The average cooling towers wet bulb approach that is defined as the difference of leaving water temperature and the ambient wet bulb temperature, was found to be of 4°F which is extremely good (A wet bulb approach below 5°F is considered good). The average thermal efficiency of cooling towers has been calculated as 57.6% which is more than the design cooling tower thermal efficiency which is around 52%.

Table 4.14 OPerformance analysis of CoolingTowers

Parameters	CT-1	CT-2	CT-3
Air discharge area (ft ^{2})	28.26	28.26	28.26
Air velocity (ft/min)	1513	1545	1596
Air flow (CFM)	42757	43662	45103
Leaving air DBT (°F)	92.4	90.1	93.3
Leaving air WBT (°F)	88.5	87.8	89.0
Leaving air enthalpy (Btu/lb.)	53.683	52.784	54.345
Entering air DBT (°F)	90.8	90.8	90.8
Entering air WBT (°F)	82.2	82.2	82.2
Entering air enthalpy (Btu/lb.)	45.897	45.897	45.897
Heat removed (Btu/hr)	1500000	1356000	1716000
Heat removed (TR)	125	113	143
Entering water temperature (°F)	91.8	91.8	91.8
Leaving water temperature (°F)	86.1	86.4	86.3
Thermal efficiency (%)	59.4	56.2	57.3
Wet bulb approach (°F)	3.9	4.2	4.1

Air Handling Units (AHUs) performance analysis

There are approximately 25 AHUs of different capacity are installed in BPCL building. Total filter area was measured and the air velocity near filter in individual AHUs was measured with the help of digital air flow meter. The supply and return air dry-bulb and wet bulb temperatures were also measured to estimate the load on individual AHUs. Simultaneously electrical parameters of AHUs' motors were also measured with the help of digital power multimeter. The detailed AHUs analysis is given in tables below.

Table 4.15 AHUs coil capacity

AHU	Return air DBT (°F)	Return air WBT (°F)	Return air enthalpy (Btu/lb)	Supply air DBT (°F)	Supply air WBT (°F)	Supply air enthalpy (Btu/lb)	Area (ft²)	Air Velocity (feet/min)	Air quantity (CFM)	Coil cooling capacity (TR)
AHU-23	77.1	67.2	31.621	62.7	60.4	26.66	29.33	315	9239	17.19
AHU-11	77.1	66.9	31.382	62.7	60.8	26.938	29.33	256	7508	12.51
AHU-10	76.8	66.7	31.225	64.9	61.8	27.629	29.33	272	7978	10.76
AHU-22	77	67.4	31.783	63.8	61.3	27.282	29.33	315	9239	15.59
AHU-21	75.7	67.2	31.633	64.7	62.9	28.424	40	270	10800	13.00
AHU-9	77.5	67.6	31.940	64.5	62	27.774	29.33	317	9298	14.53
AHU-7	80.3	70.3	34.171	69.6	66.3	30.967	20	422	8440	10.14
AHU-5	79.5	69.4	33.498	66.9	64.4	29.522	40	351	14040	20.93
AHU-16	75	66.2	30.845	67.1	63.5	28.848	20	311	6220	4.66
AHU-4	78.6	69.2	33.250	63.5	61.7	27.567	22	256	5632	12.00
AHU-3	77.9	68.7	32.839	64.2	62.7	28.282	17.33	197	3414	5.83
AHU-15	73.5	66,2	30.857	63.1	61.7	27.57	29.33	284	8330	10.27
AHU-17	75.7	66.2	30.839	64.4	61.8	27.632	29.33	327	9591	11.53
AHU-18	75.3	66.4	31.000	63.8	61.8	27.636	29.33	234	6863	8.66
AHU-19	73.4	66	30.701	63.1	61.1	27.145	40	223	8920	11.89
AHU-20	73.5	65.6	30.375	62.6	61.3	27.29	29.33	292	8564	9.91
AHU-8	77.3	66.9	31.380	64.4	61.8	27.632	29.33	321	9415	13.23
AHU-6	80.7	71.2	34.951	66.5	64.5	29.601	29.33	321	9415	18.89
AHU-12	74.7	64.9	29.842	60.6	57.9	24.989	40	425	17000	30.94
AHU-24	75.3	64.5	29.534	60.6	57.9	24.989	40	350	14000	23.86

- Total cooling produced by the AHUs at the time of measurement was 276.33 TR.

Operating and rated airflow of AHUs are given in Table 4.12 below.

Table 4.16 Rated and operating CFM

AHU	Opt CFM	Rated CFM
AHU-23	9239	11395
AHU-11	7508	5870
AHU-10	7978	9645
AHU-22	9239	9275
AHU-21	10800	9275
AHU-9	9298	12730
AHU-7	8440	8200
AHU-5	14040	5500
AHU-16	6220	9275
AHU-4	5632	2292
AHU-3	3414	4700
AHU-15	8330	9275
AHU-17	9591	9275

AHU-18	6863	9275
AHU-19	8920	9275
AHU-20	8564	9275
AHU-8	9415	7600
AHU-6	9415	5400
AHU-12	17000	3650
AHU-24	14000	11395

- The average percentage of operating airflow (CFM) in AHUs is more than the rated airflow.

Energy conservation opportunities

During energy audit it was found that the total coil capacity at the AHUs was approximately 280 TR and the cooling load at plants was 322 TR. Since the measurement was taken in the month of August and the internal building loads remain constant this could be taken as a good measure of the building peak load. This indicates that the building AC system has been designed for 400 TR. In order to produce 400 TR cooling at peak two 200-TR plants to be operated with two chilled water pumps, two condenser water pumps along with two cooling towers keeping one plant, two CHW pumps, two CDW pumps and one cooling tower as standby.

Rated system efficiency for designed building cooling load of 400 TR

Table 4.17 Energy consumed in AC equipment at design condition

Equipment	Rated kW	No. of operating equipment	Total kW
Compressors	123	2	246
CHW pumps	30	2	60
CDW pumps	30	2	60
CTs	7.5	2	15
AHUs	134.5	all	134.5
FCUs	1.95	all	1.95

Total kW/hr : 517.45 kW
Total cooling produced : 400 TR
System efficiency : 1.29 kW/TR

Operating system efficiency at operating building load of 322-TR

Table 4.18 Energy consumed in AC equipment at operating condition

Equipment	Operating kW	No. of operating equipment	Total kW
Compressors	94.3	3	282.9
CHW pumps	21	3	63
CDW pumps	25	2	50
CTs	3.14	3	9.42
AHUs	58.15	1	58.15
FCUs	1.82	1	1.82

Total kW/hr : 465.29 kW
Total cooling produced : 322 TR
System efficiency : 1.445 kW/TR

The operating system efficiency of the installed system is 1.445 kW/TR as compared to the rated system efficiency of 1.29 kW/TR that means for producing one TR of cooling the system is consuming 0.115 kW extra. Assuming the average load of the building is approximately 300 TR for whole year and the system operates for 2362.5 hours per year, this system is wasting approximately 81500 kWh.

Now we have to look for why the system operates at lower efficiency than the rated efficiency. The main observations of performance evaluation of the AC systems are listed below.

- It has been observed that during peak summer & monsoon periods (from May to August) power supply at BPCL building remains very erratic this has been indicated also by high HSD consumption in these months due to use of DG sets.
- Due to sudden power failure the whole systems come to a halt. Plants once stopped are restarted only after a gap of 20 minutes. During this time the building load gets increased and when plants are restarted it is anticipated to provide cooling very fast because since then operator has already received many complaints about discomfort in various rooms. In order to produce cooling very fast all the plants are restarted but they are run only at the 60% loading also three chilled water pumps are run in order to provide more chilled water. No doubt still only two condenser pumps operate but to take extra load three cooling towers are continuously run

round the year. Since most of the time plants generally start operating at high return chilled water temperature and they operate at part load the operating efficiency of plants remain very low as compared to their rated efficiency.

- Other parameters which affect the plant performance are chilled water flow and condenser water flow through plants and they appear to be quite close to the design flow as indicated in the above section. Also entering condenser water flow is lower than the design temperature this approves that the even cooling towers are operating at high efficiency. It is with the AHUs also since they seem to be operating at good efficiency.
- So the one reason why system-operating efficiency is low is because of low operating plant efficiency and that happens due to erratic power supply at BPCL building during peak summer & monsoon periods.

Energy saving potential in AC system due to enhanced plant efficiency

As described in the chapter of electrical system with the installation of auto changer and auto voltage regulator the problem of delay in restart of the plants can be resolved and this would enhance the operating efficiency of the plants. With enhanced efficiency, which could be assumed to be close to the rated efficiency and considerable amount of energy and cost could be saved and that details are given below.

Table 4.19 Projected energy consumption in AC equipment with enhanced plant efficiency

Equipment	Project kW	No	Total kW
Compressors	92.25	2	184.5
CHW pumps	21	2	42
CDW pumps	25	2	50
CTs	3.1	2	6.2
AHUs	58.15	all	58.15
FCUs	1.82	all	1.82

Total kW/hr : 342.67 kW
Total operating hours in a year : 2362.5
Projected consumption in a year : 809558 kWh
Present energy consumption in AC system : 978710 kWh
Energy saving potential in a year : 169152 kWh
Total annual saving of energy cost : Rs 727354

Additional energy saving potential due to enhanced operating efficiency of CHW pumps & CDW pumps

The operating efficiency of chilled water pumps and condenser water pumps were found to be 55.3% and 52.8% respectively. However, their rated efficiencies are approximately 77 to 78 %. If pumps are made operational at their rated efficiency by suitable correction, the present energy input in pumping would be reduced and this would add to the energy saving potential.

Table 4.20 Projected energy consumption in AC equipment with enhanced plant and pump efficiencies

Equipment	Projected kW	No	Total kW
Compressors	92.25	2	184.5
CHW pumps	16.6	2	33.2
CDW pumps	18.86	2	37.72
CTs	6.3	2	12.6
AHUs	58.15	all	58.15
FCUs	1.82	all	1.82

Total kW/hr	:	328 kW
Total operating hours in a year	:	2362.5
Projected consumption in a year	:	774876 kWh
Present energy consumption in AC system	:	978710 kWh
Energy saving potential in a year	:	203834 kWh
Total annual saving of energy cost	:	Rs 876480

Hence there exists an energy saving potential of 203834 kWh annually or cost saving of Rs 8.8 lakhs per year by enhancing first the operating efficiency of the AC equipment and then of whole AC system. With this the system specific power consumption would decrease to 1.09 kW/TR which is even lower than the rated system specific power of 1.29 kW/TR.

Since this energy audit was conducted during the period when power failures were frequent and at the same time all the measurement were taken to evaluate the operating performance of the AC system. It was found very difficult to establish correct correlation with comfort levels (mainly temperature, humidity and airflow) and equipment performance. Hence it is felt that BPCL management first follow the following recommendations to improve the operating efficiency of the system and monitor the energy consumption in AC system then a fresh audit should be conducted for finding out other cost intensive measures to save energy e.g. variable pumping & automation.

Recommendations for AC system

- First and foremost resolve the problem of delay in start of chilling plants during periods of frequent power failures. This may be overcome by installing auto changer & auto voltage regulator.
- Enhance the operating efficiency of chilled water pumps & condenser water pumps. This could be done with assistance of pumps' manufacturer.
- Operate only two plants with two chilled water pumps, two condenser water pumps and only two cooling towers.
- Reset the thermostat at 24 ° C in AHUs as compared to the existing lowest setting, which is done in order to achieve fast cooling at the time of erratic power supply.
- Monitor plant consumption and system consumption on daily basis. A separate submeter can be installed at AC panel for this.
- Conduct a fresh energy audit of AC system after one year of smooth operation of AC system.